Advanced Development of a Laser Bathymetry System: L-Bath

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LONG-TERM GOALS

The long range goals of this program fall into several areas: 1) Operational, 2) Scientific, 3) Computational. In an operational sense, we seek to demonstrate the feasibility and field deployable ability of a new type of 3-dimensional underwater imaging system which is based on using solid state components instead of mechanical ones. In a scientific sense we seek to understand the propagation of light in the coastal environment in which this imaging system will operate. This will include the deployment of the system in the COBOP field program and will take advantage of the large amount of auxiliary data that will be collected in this program. In a computational sense, we seek to develop processing algorithms to optimize the quality of information that is being sensed optically. Using the output from the solid-state imaging array, we will be able to construct a record of the time varying radiance that is incident upon the camera. Using this information in conjunction with the environmental data that will be collected, we will test the system's capability to simultaneously estimate both the environment and also the reflectivity and topography of the bottom, especially with respect to finding man made items.

OBJECTIVES

The objective of this past year of our program has been to continue our studies with our existing instrumentation to expand, develop and explore the use of the system. Data from past field operations has been analyzed and new algorithms for processing the information have been created.

APPROACH

The period covered by this report consisted of 3 months. During that time, we continued our technical approach for the advanced development of the system has been to continue characterizing the capability of the system to image three dimensional objects on the sea floor. Algorithms were tested on data sets that were collected under very precisely controlled situations in our lab and then generalized to the field data sets which were collected during the field expeditions.

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14. ABSTRACT
The long range goals of this program fall into several areas: 1) Operational, 2) Scientific, 3) Computational. In an operational sense, we seek to demonstrate the feasibility and field deployable ability of a new type of 3-dimensional underwater imaging system which is based on using solid state components instead of mechanical ones. In a scientific sense we seek to understand the propagation of light in the coastal environment in which this imaging system will operate. This will include the deployment of the system in the COBOP field program and will take advantage of the large amount of auxiliary data that will be collected in this program. In a computational sense, we seek to develop processing algorithms to optimize the quality of information that is being sensed optically. Using the output from the solid-state imaging array, we will be able to construct a record of the time varying radiance that is incident upon the camera. Using this information in conjunction with the environmental data that will be collected, we will test the system's capability to simultaneously estimate both the environment and also the reflectivity and topography of the bottom, especially with respect to finding man made items.

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WORK COMPLETED

Efforts were expended towards a post procesing of the data that we had collected in our previous field expeditions and also lab studies.

RESULTS

One project that was pursued was an imaging processing technology which would allow the extraction of not only the bottom reflectivity but also the environmental parameters. Since line scan systems collect their data on a point by point basis they measure a local impulse response of the medium which includes both attenuation and scattering. Here, it is proposed that the estimation of this impulse response can be used to jointly estimate attenuation, both volume and small angle scattering, and also the features of the bottom that are of interest. So, for example, the estimation of the range is dependent upon the location where the laser beam was incident on the bottom. The light reflected from the bottom is both spread and attenuated after reflection. Knowledge of both the coefficients associated with spreading (the small angle scattering components) and the attenuation can be used to predict the radiance profile which would be observed, given guesses for these parameters. Since the physical parameters of the medium should be constant for a given experiment, they can be estimated using a procedure which refines the observed data against a model of the both bottom and the medium. Moreover, an algorithm which estimates the water parameters is capable, in principle, of producing images which are of higher quality than one which does not take the medium properties into account.

Mathematical Model

In an identical way to other line scan systems, the system collects data by scanning the beam in the same plane as the field of view of the CCD imaging system by sweeping the laser beam across the field of view of the camera. For each laser pointing angle, a vector of 1024 values are collected, the output of the CCD chip. Scanning the laser over a set of angles creates a two dimensional matrix which contains the reflected light, as sensed by the CCD array, as a function of element number and also laser position. Mathematically, this array can be represented as I(x,n) where x corresponds to the element number in the CCD chip and n corresponds to the n^{th} pointing angle of the laser for this single scan.

In order to compute the system response to the incident light, a system of equations are formulated. Note here that the effects of attenuation and spherical spreading are disregarded. First, assume that irradiance pattern of the light on the surface of the target (without any medium spreading) can be represented as $\mathrm{BPI}(\theta,\mathrm{R})$. Next, assume that the result of the light propagating through the medium can be represented by a spreading operator or, convolution with a Beam Spread Function. The radiation incident on the target can then be described as: $\mathrm{BPI}(\theta,\mathrm{R})\otimes\mathrm{BSF}(\theta,\mathrm{R})$. The light reflected from the surface reflection map $\rho(\theta,\mathrm{R})$ (in the source coordinates) results in a reflected pattern of: $\rho(\theta,\mathrm{R}) \bullet \mathrm{BPI}(\theta,\mathrm{R})\otimes\mathrm{BSF}(\theta,\mathrm{R})$. Now, the resulting image on the camera can be computed by regarding the reflected light as that due to an unresolved Lambertian reflector and therefore, the image of the light that is incident on the camera is: $PSF(\theta,R)\otimes(\rho(\theta,\mathrm{R}) \bullet \mathrm{BPI}(\theta,\mathrm{R})\otimes\mathrm{BSF}(\theta,\mathrm{R}))$, where $\mathrm{PSF}(\theta,\mathrm{R})$ is the point spread function of the medium. Note that the n^{th} position of the scanning laser beam can be represented as $\mathrm{BPI}(\theta-n\Delta\theta,\mathrm{R})$ so that the expression for the irradiance as measured by the camera (neglecting attenuation and spherical spreading) can be represented as:

$I(x,n) = PSF(\theta,R) \otimes (\rho(\theta,\mathrm{R}) \bullet \mathrm{BPI}(\theta - n\Delta\theta,\mathrm{R}) \otimes \mathrm{BSF}(\theta,\mathrm{R}))$. An additional feature of any real experiment will also be the presence of volume scatter. The volume scatter considered here (considering only singly scattered photons) is due to the backscatter produced by the interaction of the laser with the volume. It is modulated by the strength of the volume scattering function, a function of angle between the incident and scattered photons. Adding a term for volume scanning: V(θ,R) the expression is: $I(x,n) = PSF(\theta,R) \otimes (\rho(\theta,\mathrm{R}) \bullet \mathrm{BPI}(\theta - n\Delta\theta,\mathrm{R}) \otimes \mathrm{BSF}(\theta,\mathrm{R})) + \mathrm{V}(\theta,\mathrm{R})$. The purpose of the signal and image processing techniques is to invert for ρ(θ,R) given the observation matrix, *I(x,n)*.

Obtaining an estimate of the inherent optical properties

In this section it is demonstrated that an estimate of the volume scattering function can be obtained from collected data. In addition, the identical data set used in that publication was also used here for analysis. The two data sets consist of a of a small white target on a black background and a small black target on a which background. The target was imaged in a variety of different water conditions with extinction coefficients of 0.593, 0.81, 1.18, 1.28, 1.51. Companion ranges in total attenuation lengths are 2.25, 3.09, 4.5, 4.87 and 5.73 at 3.83 meters range.

Figure 1 shows a graph of the experimental configuration. The target is imaged at a range of 3.83 meters. Separation between the camera and the laser beam is 1.1 meters. The laser beams sweeps across the field of view of the camera which subtends ~2 m at this range. The figure illustrates that the light collected by the system occurs from two sources: (1) light that is volume scattered (backscattered) from particles within the water column and (2) light reflected from the target. After reflection from the target, the light undergoes small angle scatter. Note that this treatment neglects multiply scattered photons.

Volume Scattering Function (large angle)

In order to obtain an estimate of the volume scattering function over the observable range of values, the collected data was processed. As described above, the observed irradiance pattern is a superposition of two features, (1) the point spread function of the medium after reflection by the surface and (2) the light that has been backscattered. With reference to Figure 1, the field of view of the camera system can be divided into two halves, a right half and a left half. In the right half, the observed signal is a superposition of the reflected light and the backscattered light. In the right half, the signal is only due to the reflected light after convolution with the point spread function of the medium.

Under this theory of a simple superposition, subtraction of the left half from the right half should result in an irradiance pattern that is simply due to the backscatter. Under this hypothesis, the left half was subtracted from the right half and the remaining irradiance was considered to a result of single volumetrically scattered photons. The angle between the source and receiver was used to determine the angle of the volume scattering function which was governing this observation and the range from the source receiver plane was used as an additional index. The figure shows a graph of the observed value of volume scatter at a given range and from a particular angle for the data where the total attenuation coefficient was measured to be 1.18 m^{-1}. Based on the geometry of the source, receiver and the target the accessible region for the observation of the volume scattering function was between angles of 5.85

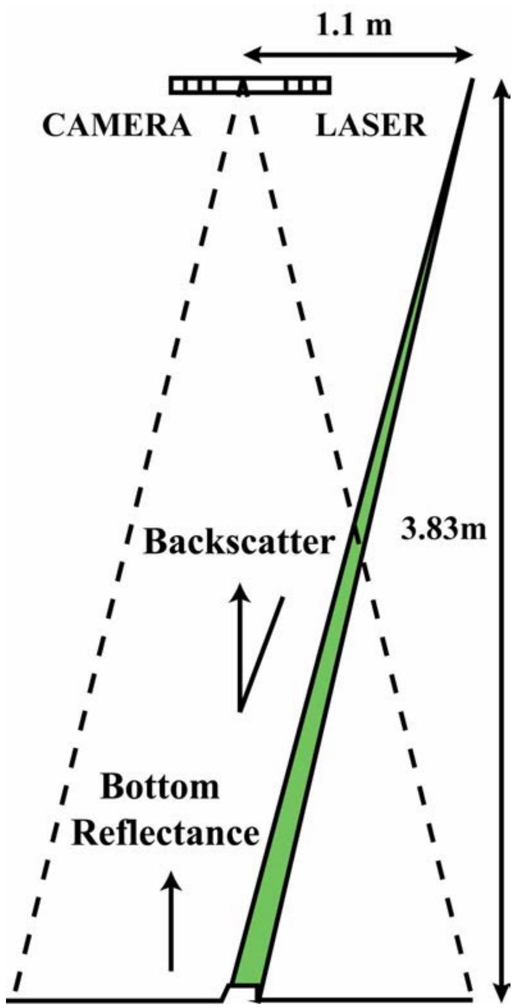

Figure 1: The basic geometry for the experiments considered in this abstract. Note the accessible region of the volume scattering function due to the angle between the laser beam and the receiver.

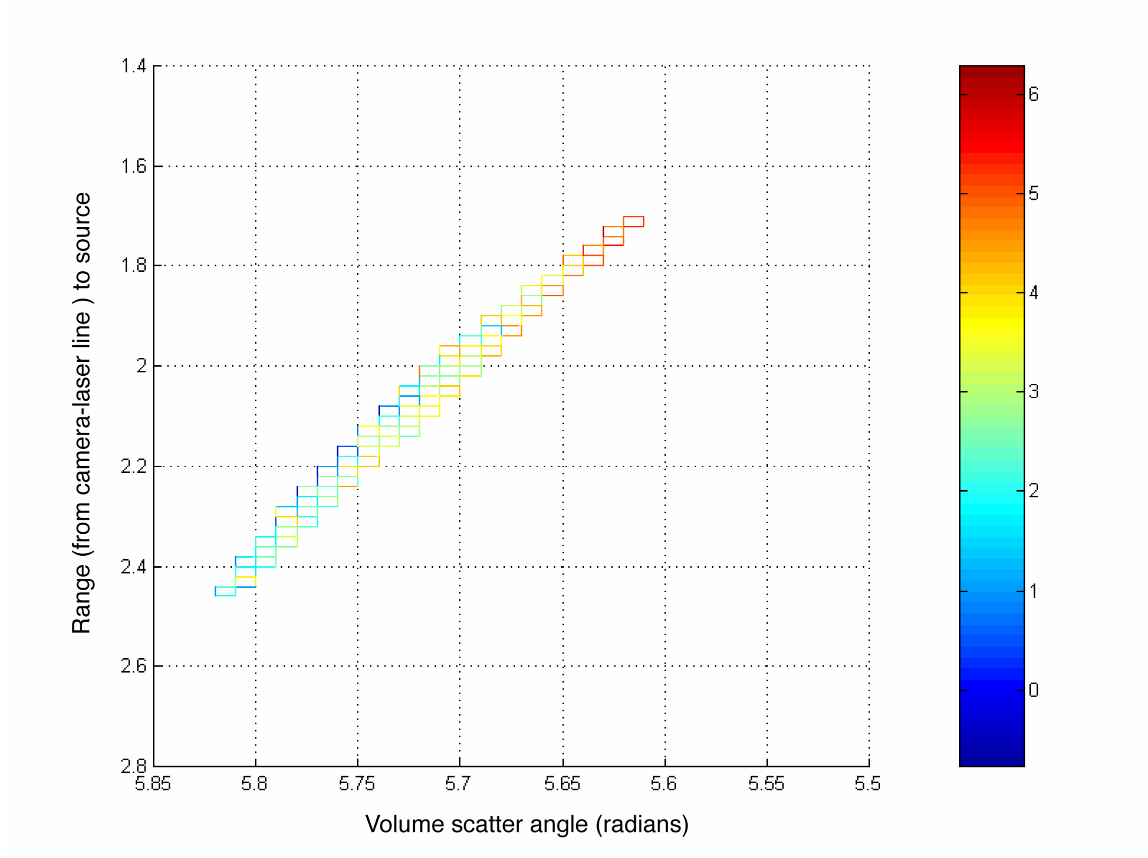

Figure 2: A graph of volume scatter as derived via the algorithm described in the text. The horizontal axis is the volume backscatter angle and the vertical axis is the range at which the backscatter was measured in meters. The scale is digital units of irradiance as measured by the camera system.

and 5.55 radians. The observed ranges were between 1.6 and 2.6 meters. Future treatment of this data will be to formulate an exact estimate for the volume scattering function using this data.

IMPACT/APPLICATIONS

To our knowledge, we have developed the most detailed three dimensional system for viewing objects at extended range in the sea using light. The system demonstrates that extended range imaging can be achieved by using structured lighting techniques. Potential future areas for the use of the system are for studying benthic systems, including bottom turbulence induced by bottom roughness.

TRANSITIONS

Since this is a technology development program we have been in contact with companies that are interested in our work. In addition, we have demonstrated our results to personnel at the Naval Coastal Systems Center in Panama City, FL.

RELATED PROJECTS

We have worked with a program that has been sponsored by the acoustics, biological oceanography and geology division of ONR to scatter sound from the sea floor. A 10 day deployment there resulted in the observation of bottom bathymetry to submillimeter resolution with time intervals as short as minutes.

PUBLICATIONS